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Review

Basis for Formulation of Fertilizer Recommendations for Crop Production

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ABSTRACT

Soil organic matter is low in agricultural soils of Pakistan and thus has less inherent fertility. Moreover, most of the nutrients present in soils are organically bound. Only the small fraction of nutrients is in inorganic form that is available for direct uptake by plants. Nutrients requirement increased with the introduction of high yielding varieties and also due to high cropping intensity. Therefore, it is necessary to apply the fertilizer according to the need of the crops otherwise it not possible to get the good crop growth and optimum yield. Different approaches used to increase the crop yield by formulating the fertilizers requirements for different crops are reviewed in this paper.

Key Words: Fertilizer; Crop production; Recommendations

INTRODUCTION

Fertilizers are an essential agricultural input for increasing the crop productivity. Plant nutrients are neither adequately available from soil reserves nor can they be procured in sufficient amount from alternative sources like organic manures, crop residues or bio-fertilizers. Therefore, fertilizer use must be increased to supply the nutrients for increasing food grain production needed to feed the growing population at acceptable nutritional levels. Well-managed fertilizer use can create a "Win-Win" situation by increasing food production and reducing soil degradation in nutrient poor fragile soils. Today the major goal of sustainable agriculture is to maintain production at levels necessary to meet the increasing aspiration of an expanding country population without degrading the environment. Adequate and balanced supply is a pre-requisite to optimum plant growth and realizing potential crop yield. As most soils are generally deficient in one or more nutrients, optimum nutrition can be assured only by balanced fertilizer application. Balanced nutrition of crops can only be ensured if the nutrients application is based on actual nutrient requirement of crop and the nutrient supplying capacity of the soil on which the crop is grown. This necessitates that sustainable crop production involve appropriate management of nutrients and nutrient resources for agriculture while maintaining or enhancing the quality of environment.

The main governing principle of any nutrient management strategy based on sound fertilizer recommendation for sustainable crop production is to enhance the fertilizer use efficiency by ensuring the maintenance of soil fertility without any compromise on environmental degradation. The main objective of this review paper is to discuss the basis for the formulation of fertilizer recommendation for sustainable crop production.

Nutrient elements required for plant growth. Soil fertility refers to the inherent capacity of a soil to supply nutrients to plants in adequate amounts and in suitable proportions. An element is considered as an essential plant nutrient on the basis of the criteria:

i) A deficiency of the element makes it impossible for the plant to complete its life cycle
ii) The deficiency is specific for the element in question
iii) The element is directly involved in the nutrition of plant as a constituent of an essential metabolite or required for the action of an enzyme system.

Based on the criteria proposed by Arnon and Stout (1939), the elements, C, H, O, N, P, K, S, Ca, Mg, Na, Cl, Si, Mo, Zn, B, Fe, Mn and Co are known to be essential. The plant nutrients are divided into macronutrients and micronutrients. The macronutrients are further classified:

i) Major nutrient elements (carbon, hydrogen, oxygen), taken up by plants from air and water
ii) Primary plant nutrient (Nitrogen, phosphorus and potassium)
iii) Secondary plant nutrients (sulphur, calcium, magnesium).

Nitrogen is taken up by plants as NO_3^- or NH_4^{++}, phosphorus as $H_2PO_4^-$ and potassium as K^+. Secondary nutrients such as sulfur, calcium, and magnesium are taken up by plants as SO_4^{2-}, Ca^{2+} and Mg^{2+}, respectively. Among the micronutrients, boron and chloride are taken up as H_3BO^{3-} and Cl^{2-}, respectively. Rest of the micronutrients such as copper, iron, manganese, molybdenum and zinc are taken up as divalent cations.

Nutrient elements of agricultural significance in Pakistan. In agricultural soils of Pakistan, organic matter levels are quite low ranging from 1.2% in cool mountainous area to 0.2% in dry hot climatic region. Inherent fertility status, especially of nitrogen, is quite low to low organic matter (Zia, 1990). Thus, almost all crops, except some leguminous, require the use of nitrogenous fertilizer for proper crop production. Majority of soils are low to medium in P (Memon, 1986). Because most of the soils in Pakistan are alkaline and calcareous in nature and have bad affect on P availability to plants. Therefore, successful crop production demands judicious use of P fertilizers. Mica (K bearing mineral) is one of the dominant clay minerals in most of the agricultural soils of Pakistan. Its prevalence in soils clearly indicates abundance of K reserves in natives soils (Ranjha, 1988). Among the micronutrient, Zinc deficiency ranks at the top as about 70% soils in Pakistan are low in Zn content (Hussain & Rashid, 1979; Zia, 1990). Deficiencies of other nutrients such as boron and iron have also been reported because of increasing cropping intensity (Rashid & Rafique 1999).

Diagnosis of fertilizer requirement. The growth and the yield of crops depend upon the ability of soil fertility. Several approaches are employed for assessing the crop nutrient requirements, some of which are as under:

A. Optical plant nutrient deficiency symptoms. Deficiency of nutrient in the soil will affect the normal growth of the plant. As a result plant exhibit characteristic symptoms when a nutrient is present in insufficient quantity for normal growth and these symptoms can be used to diagnose the nutrient deficiency. The optical symptoms can be quite specific in pinpointing nutrient deficiencies. A brief key determining deficiency symptom is given in Table I. However this technique has some disadvantages,

i) Deficiency symptoms must develop before they can be identified and it may then be too late, especially with annual crops to apply remedial measures for that crop.

ii) Symptoms of certain deficiencies are not very distinct and may be visible only when the deficiency is acute

iii) Deficiency symptoms may be suppressed by such factors as whether or pest and disease incidence (FAO, 1984).

Table I. Key to deficiency symptoms

Symptoms	Deficiency
Symptoms appearing first on older leaves:	
Chlorosis starting from leaf tips	N
Necrosis on leaf margins	K
Chlorosis mainly between veins (which remain green)	Mg
Brownish, grayish, whitish spots (i.e., on cereals)	Mn
Reddish color on green leaves or stem	P
Symptoms appearing first on younger leaves	
Mottled yellow-green leaves with yellowish veins	S
Mottled yellow-green leaves with green veins	Fe
Brownish black spots (i.e. on legumes, potatoes)	Mn
Youngest leaf has white tip	Cu,
Youngest leaf is brownish or dead (i.e., on beet)	B

Source: FAO, 1984.

B. Soil testing/analysis. Soil testing is a better method than deficiency symptom and plant and tissue analysis, because it helps in determining the nutrient need of the plant before the crop is planted. It is simpler and less time consuming than other methods. The main objectives of soil analysis are to assess the nutrient status of soil and diagnostic problems of salinity/sodicity and to quantify the gypsum requirement if needed. Further, soil tests measure some fraction of total supply of nutrient and indicate its available nutrient level that determines the amount of fertilizer nutrients required. The success or failure of the soil test depends on securing a representative soil sample, its subsequent handling and proper soil test method. Soil tests values are of little use unless properly calibrated against crop response to applied fertilizers in field experiments.

C. Plant analysis. In case of plant analysis, collection and handling of samples are more critical than soil analysis. In addition to the sample being representative, care must be taken in selecting correct plant part, the growth stages of the crop and even the time of the day and growing conditions. Plant analysis means to analyze a plant or plant part for assessing its nutrient status. Plant analysis is based on the concept that the concentration of nutrient in diagnostic plant parts indicates the soils ability to supply that nutrient and is directly related to the available nutrient status in the soil. It is useful tool for monitoring nutrient levels at various growth stages and also helpful to establish the deficiencies and toxic level of elements.

D. Interpretation of soil and plant analysis. The intensity of a nutrient less than that the crop yield or performance decreased below optimum is called the critical level of that nutrient. Traditionally, soil and plant analysis data are interpreted using critical levels approach. Critical levels have been established for different soil test methods and for crops that refer to specific growth stages and plant parts. General guidelines for critical, sufficient and toxic level of soil and plant nutrients (Bennet, 1993) are given in the Table II and III.

Table II. Generalized guidelines used for interpretation of soil analysis data in Pakistan

Nutrient	Soil test	Unit	Low	Medium	Adequate	Reference
O.M.	Walkley and Black	%	<0.86%	0.86-1.29%	>1.29%	FAO(1980)
$N0_3$-N	AB-DTPA	mg kg^{-1}	<10	10-20	>20	Soltanpour (1985)
P	$NaHCO_3$	″	<10	10-15	>15	Ahmed *et al*. (1991)
	AB-DTPA	″	<3	4-7	>7	Soltanpour (1985)
K	NH_4OAc	″	<50	50-125	>125	Wahhab (1985)
	AB-DTPA	″	<60	60-120	>120	Soltanpour (1985)
Zn	DTPA	″	<0.5	0.5-1.0	>1.0	Martens and Lindsay (1990)
	AB-DTPA	″	<0.9	0.9-1.5	>1.5	Soltanpour (1985)
Cu	DTPA	″	<0.2	-	>0.2	Martens and Lindsay (1990)
	AB-DTPA	″	<0.2	0.2-0.5	>0.5	Soltanpour (1985)
Fe	DTPA	″	<4.5	-	>4.5	Martens & Lindsay (1990)
	AB-DTPA	″	<3.0	3.0-5.0	>5.0	Soltanpour (1985)
Mn	DTPA	″	<1.0	1.0-2.0	>2.0	Martens & Lindsay (1990)
	AB-DTPA	″	<0.5	0.5-1.0	>1.0	Soltanpour (1985)
B	Hot water	″	<0.5	0.5-1.0	>1.0	Johnson & Fixen (1990)

Diagnosis by fertilizer additive /graded doses. Soil test calibration studies are primarily carried out to workout fertilizer requirements on regional basis. The plant in its natural environment is the final judge of what element is available or not. Field experiments provide yield response to graded rates of applied nutrient and used to determine the fertilizer rate at which economic crop yield can be obtained. Field trials are also used to calibrate any diagnostic test for this purpose.

Developing fertilizer recommendations. Soils vary in their capacity to provide nutrients to crops and crops differ in their requirements, therefore, most soils cannot supply all essential nutrients to crops. Fertilizers recommendations are therefore, developed to quantify the amount of nutrients for various crops which are to be applied through fertilizers. Fertilizer recommendations are of two types:

i) General recommendation
ii) Scientific site-specific recommendation.

General recommendations. The average values of crop response at several typical locations of the area to graded doses of fertilizers provide the basis for formulating fertilizer recommendations. Crop response are evaluated and interpreted on the basis of economics, level of soil productivity, previous cropping, soil texture and irrigation or rainfall. Organizations involved in conducting field crop response studies, extension specialist and the farmers formulate fertilizer recommendations at provincial level on the basis of pooled data and the experience of extension specialist and the farmers.

Nutrient requirements of different crops varied widely and even the varieties within one crop also have different nutrient requirements due to genetic variation (Ahmad *et al*., 1996, Table IV). Formulation of fertilizers recommendation is a continuous process. Nutrient depletion, change in crop variety, changes in cultural practices, changes in crop/input price ratio, or changes in cropping intensities necessitate revision and updating of fertilizer recommendations. In fact continuing studies are needed to refine recommendations and correct nutrient imbalances. Long-term studies are

Table III. General guidelines for deficient sufficient, and toxic levels of nutrients in plants

Elements	Unit	Deficient level	Sufficient range	Toxicity level
N	(%)	< 2.0	2.0 - 5.0	Non - toxic
P	(%)	< 0.2	0.2 - 0.5	Non - toxic
K	(%)	< 1.0	1.0 - 5.0	Non - toxic
Ca	(%)	< 0.1	0.1 - 1.0	Non - toxic
Mg	(%)	< 0.1	0.1 - 0.4	Non - toxic
S	(%)	< 0.1	0.1 - 0.3	Non - toxic
Fe	(ppm)	< 50	50 - 250	Non - toxic
Zn	(ppm)	15-20	20 - 100	> 400
Mn	(ppm)	10-20	20 - 300	> 300
Cu	(ppm)	3-5	5-20	>20
B	(ppm)	< 10	10 - 100	> 100
Mo	(ppm)	< 0.1	0.1 -0.5	> 0.5
Cl	(%)	< 0.2	0.2 - 2.0	> 2.0
Si	(%)	< 0.2	0.2 - 2.0	Non - toxic
Na	(%)	< 1.0	1.0 - 10	Non - toxic
Co	(ppm)	< 0.2	0.2 - 0.5	> 0.5
V	(ppm)	< 0.2	0.2 - 0.5	> I

Source: Bennett, 1993

Table IV. Fertilizer requirement of major crops

Crop	Province	N	P_20_5	K_20
Wheat (irrigated)	Punjab	75-160	60-110	60
	Sindh	130-170	60-90	50
	NWFP	120-150	40- 190	50
	Balochistan	90-120	60	30
Wheat Rainfed (high rainfall > 500 mm)		100-110	80-85	30-60
Wheat Rainfed (low rainfall < 500 mm)		57-85	50-60	60
Rice (IRRI Type)	Punjab	120-150	60-90	50
	Sindh	120-80	60-90	50
Rice (Basmati Type)	Punjab	50-100	60-75	50
	Sindh	80-100	60	-
Sugarcane	Punjab	170-270	60-110	60-120
	Sindh	200-300	100-125	100-170
	NWFP	120-175	100	100
Cotton	Punjab	112-170	60	60
	Sindh	90-140	60	60
	NWFP	60-80	60	60
Maize -(Irrigated)	Punjab	90-170	90-120	60-90
	Sindh	120-160	75	50
	NWFP	90-120	75	50
Maize (Barani)	Punjab	60-90	60	-
	NWFP	90-120	60-90	30-60

Source :- Ahmad *et .al*., 1996.

Table V. Fertilizer Recommendation for Wheat – An Example Recommended fertilizer rates in relation to soil nutrient status for a yield target of 4 t ha^{-1}

Soil test $KmnO_4$-N (kg/ha)	Fertilizer rate (kg N/ha)	Soil test Olsen's P (kg/ha)	Fertilizer Rates (kg P_2O_5/ha)	Soil test Amm. Acetate-K (kg/ha)	Fertilizer rate (kg K_2O/ha)
200	124	5	118	50	103
240	94	15	85	75	76
280	64	25	51	100	48
320	34	35	18	125	20
360	0	40	0	150	0

Source: Randhawa and Velayuthem 1982

Table VI. Nutrient removal by different crop

Crop	Yield target (t/ha)	N	P_2O_5	K_2O	S
Wheat	1	25.0	9.0	33.0	4.7
Rice	1	20.0	11.0	30	3.0
Maize	1	20.0	-	-	-
Potato	100	250-450	30-65	350-550	40
Sugarcane	1	1.2	0.46	1.44	0.25
Wheat	4	100.0	36.0	142	16.8
Rice	4	80.0	44.0	12	12.0
Maize	4	80.0	-	-	-
Potato	400	1000-1800	120-260	1400-2200	160

IFA (1992)

Table VII. Soil test critical P levels and proposed fertilizer rates

Category	$NaHCO_3$-P (mg/kg)	Recommended fertilizer dose (kg P_2O_5/ha)			
		Full tech. Adoption		Partial tech. Adoption	
		I	R	I	R
Very low	<5	90-120	75	75	60
Low	5-10	75	50	60	40
Medium	10-15	60	40	40	20
High	15-20	40	20	20	-
Very high	>20	20	-	-	-

Source: Ahmad *et al*., 1991; I= Irrigated, R= Rainfed

useful tool to get additional information for rationalize the recommendations.

Site specific recommendations. Soil tests provide scientific basis of fertilizer recommendations. These fertilizer recommendations are related to fertility status of soil of that particular location, soil type, previous cropping, use of organic manures and crop features such as variety and yield level. Thus fertilizers recommendations are referred to site-specific recommendations. Soil test based fertilizer recommendations are the most efficient method of fertilizer recommendations for crop production. It helps to avoid the application of fertilizers on fertile soils, where no responses to fertilizer application are expected. Fertilizer such saved can be applied on soils with poor fertility status where substantial crop responses are expected. An example of soil test based fertilizer recommendation for nitrogen, phosphorus and potassium is given in Table V. It is very clear from the data that application of NPK decreased as the level of nutrient in soil increased (Randhawa & Velayuthem, 1982).

Series of the field experiments were carried out on experimental farms and farmers field on graded doses of the experiments for the development of recommendations on optimum amounts of fertilizer. These experiments include a range of fertilizer treatments, sources of fertilizers and its application at various plant growth stages. Comparison of the results enable conclusion to be reached on optimum rate and application time of fertilizer. Each experiment gives definite result for the field and crop on which is conducted.

By carrying out a series of experiments, it is possible to establish the variability in fertilizer requirements from field to field and to correlate this variability with soil properties and other features recorded at that experimental site.

Crop removal of nutrients. The amount of nutrient removed in the harvested crop varies very much between crops (Table VI) and is closely related to yield level. It is therefore, necessary to take nutrient removal into account and in particular to ensure that fertilizer recommendations maintain the nutrient status of intensively cropped high yielding soils.

Adjustment of fertilizer doses. Recommendation of nitrogen fertilizer is not the same for all crops. It varied from crop to crop. This recommended level of fertilizer can be adjusted at any location by keeping in view its cropping history. Fertilizer should be applied in the higher range of the recommendation to crops if directly sown after exhaustive crops like wheat, rice, maize millets and sugarcane etc. While after fallow and pulses, keep in the lower range of fertilizer recommendation. Leguminous crops like berseem, alfa alfa, etc have ability to fix the atmospheric nitrogen. Some portion of the fixed N is also available to next crop, therefore, reduce the N application by 50 kg ha^{-1}. Farm yard manure is most important source of organic nutrients; therefore, reduce by 20 kg N ha^{-1} if well rotten farmyard manure has been applied.

The available phosphorus in the soil can be determined by soil analysis and the recommended dose can be adjusted accordingly as illustrated in Table VII and VIII. Further, before applying the phosphorus, it should also be considered that what amount was applied to previous crop because of its

Table VIII. Phosphorus fertilizer adjustment depending upon soil test levels

Soil test value	Adjustment
Low (less than 8 ppm)	Full recommended dose, higher range
Medium (8-15 ppm)	Cotton – reduced to 1/2 of recommended dose of phosphorus Other crops - recommended medium dose
High (more than 15 ppm)	Cotton - 3/4 of the recommended (Maintenance) Other crops: reduction to 3/4 or 1/2 recommended dose

residual effect on the following crop. If the Rabi crop has been fully fertilized, soil test value is over 10 mg kg^{-1}, the dose of P to following cotton or rice may be reduced to about 50%.

Many experiments in Pakistan have given responses to potassium and requirement of the nutrient is likely to grow. Apply potassium only after soil test. Potassium is most important on light textured soils, directly after exhausting crops. Potassium is generally applied to sugarcane, bananas, tomatoes and tobacco. Further, if aim at high yields and growing two crops per year apply potassium at least in one of the seasons. Zinc is deficient in most of the rice growing areas; therefore, 10-15 kg ha^{-1} zinc sulphate should be applied to all rice varieties to get the good crop yields. Zinc application has also residual effect and it should be applied to wheat crop only on soil test basis.

Experiments have shown that crops on saline soils also respond well to fertilizers, especially phosphorus. However, if a serious yield reduction because of salinity is expected, reduce the nitrogen dose but keep to the phosphorus and potassium recommendations. In connection with gypsum application, the nitrogen dose should be kept in the higher range. The key point to decide the dose in these soils should be plant population.

Fertilizers give good economical return in rainfed condition. Fertilizers do not "burn" the crop or increase the water requirements, as was earlier thought. Follow the special barani recommendations in accordance with the rainfall pattern of the area. Reduce the NP fertilizer dose in case of restricted water supply but do not apply less than half.

Lack of cash or credit situation is a serious constraint to fertilizer use, which limits the ability of the farmers to follow recommendations. Strive to obtain sufficient credit. The return on an investment in fertilizers is high and safe. It is necessary to reduce the rates of fertilizers. Economic analysis of experiments shows that return on investment often is higher at low rates of application, but total profit is less.

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